



CLIVAR/CO₂ Repeat Hydrography Program. Initial Results in the North Atlantic Ocean



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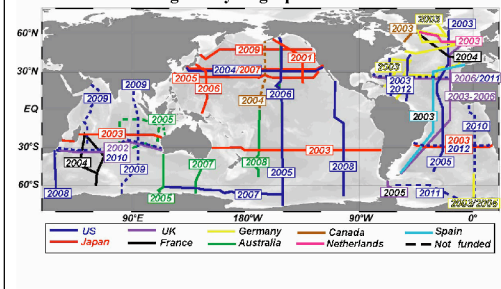
Objectives:

- Data for Model Calibration and Validation
- Carbon System Studies
- Heat and Freshwater Storage and Flux
- Deep and Shallow Water Mass and Ventilation
- Calibration of Autonomous Sensors

Approach:

The Repeat Hydrography CO₂/tracer Program is being implemented to maintain decadal time-scale changes in ocean transports and inventories of climatically significant parameters. The sequence and timing for the sections takes into consideration the program objectives, providing global coverage, and anticipated resources. The sections have been selected so that there is roughly a decade between them and the WOCE/JGOFS global survey.

Global map of planned Repeat Hydrography CO₂/tracer Program hydrographic sections

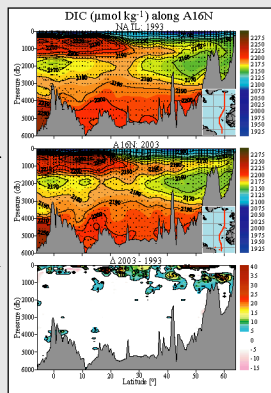


Achievements:

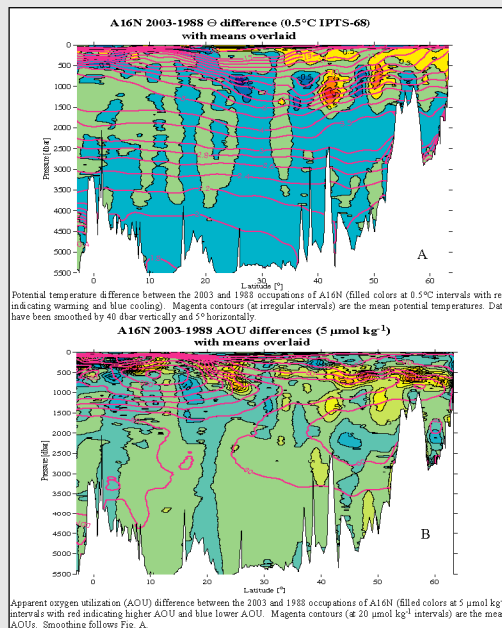
A16N:

In the two-month period between June and August 2003, the first survey (Repeat Hydrography Section A16N) as part of the Repeat Hydrography CO₂/tracer Program was successfully completed in the North Atlantic on NOAA Ship *Ronald H. Brown*. The cruise ran from Iceland southward past the equator and repeated an oceanographic section occupied in 1988, and again in 1993, looking for possible changes in the physics, chemistry and biology of the ocean in this region. The sampling rosette/CTD system worked without failure for 150 deep ocean casts, providing ~ 5000 water samples for analysis.

The figure to the right shows the A16N DIC sections occupied in 1993 (top), 2003 (middle) and the 2003 - 1993 difference (bottom). The increases in DIC between 1993 and 2003 indicate that the upper and mid-thermocline waters in this region of the northern North Atlantic are rapidly accumulating anthropogenic CO₂ on decadal time scales. The significant DIC increase of about 5 - 22 $\mu\text{mol kg}^{-1}$ at intermediate depths from about 100 - 800m north of ~ 20°N reflect, in part, the rapid uptake and transport of anthropogenic CO₂ in this water mass. Mode waters in the North Atlantic Ocean are formed each winter by cooling and convective mixing. A lack of strong wintertime mixing north of 20°N during the latter half of the decade of the 1990s (NAO positive phase) may have caused the anthropogenic CO₂ to be trapped in this layer and retained there for periods of several years.



There are a few significant patterns in the differences of water properties both physical (e.g., temperature, Fig. A) and biogeochemical (e.g., apparent oxygen utilization, AOU, Fig. B) between the 2003 and 1988 reoccupations of A16N, a meridional section in the eastern basins of the North Atlantic.



1. Warming of ~ 0.5°C is evident between Iceland and 32°N from 100 and 700 dbar (Fig. A). This warming is found within local mode waters (indicated by the widely spaced isotherms in the vertical starting near 7°C off Iceland and ending near 14°C by 32°N). The pattern suggests that in the ventilation time-period (roughly 5 years) prior to 2003 conditions were warmer, and these waters were less vigorously ventilated, than in the 5 years prior to 1988. Over the same latitude range, but between 300 and 1000 dbar, the AOU has risen between the 2003 and 1988 occupations (Fig. B). This increase in AOU within the oxycline is again consistent with less vigorous ventilation in the mode waters in the years prior to 2003 than in those prior to 1988.

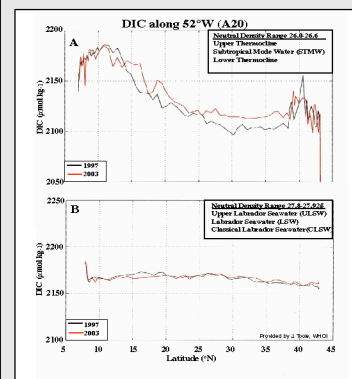
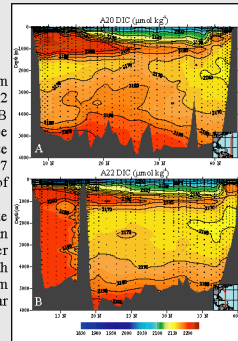
2. The oscillating temperature (Fig. A) and AOU (Fig. B) differences between 20°N and 55°N from 600 - 1600 dbar are found within the influence of the Mediterranean outflow water, and likely represent mesoscale eddy variability.

3. The colder (Fig. A), lower AOU (Fig. B) and fresher (not shown) water between 40°N and Iceland from 1600 - 2600 dbar (near 3 - 3.5°C) reveals variability in the LSW penetrating to the eastern basins of the North Atlantic. LSW was more vigorously ventilated in the years leading up to 2003 than in the years prior to 1988, consistent with the water property patterns observed.

A20/22:

The DIC results from the A20 and A22 cruises (Figs. A and B respectively) can be compared to cruise results from the 1997 WOCE occupations of these sections.

The results indicate significant increases in the shallow water masses over the depth range of 100 - 600m during the 6 year period.



Along the 26.0 - 26.6 neutral density field on 52°W (A20), DIC increases of 2 - 20 $\mu\text{mol kg}^{-1}$ were observed over the six year period between the two cruises (Fig. A). In contrast, the DIC changes at a deeper density horizon (27.80 - 27.93) showed very little change (Fig. B). These increases of DIC in the Subtropical Mode Water (STMW) may be the result of decadal changes in the local circulation, invasion of anthropogenic CO₂ into the interior North Atlantic, and/or changes in new production and remineralization of organic matter along the flow path. As we continue to process the physical and biogeochemical results from these cruises, we should be able to determine the large-scale changes in the carbon content of the Atlantic Ocean.

Future Directions:

The observational efforts to detect changes in water column inventories and to attribute the causes, and the development of basin wide CO₂ transport fluxes are part of well documented and justified integrated carbon plans. The CLIVAR/CO₂ Repeat Hydrography Program has a series of cruises planned for the next decade that will yield sequential basin wide inventory changes for the Atlantic, Pacific, Southern and Indian oceans. The cruise sequence is shown in the above figure at the top of the poster. NOAA/COSP has the lead on the cruises for A16S, A16N, P16N, P18 and I8. The NOAA CO₂ Science Team will begin the synthesis of these data sets beginning this fall. We will coordinate the cruise plans and logistics through the International Ocean Carbon Coordination Project (IOCCP).